APPENDIX H

Concept of Operations (CONOPs)

DRAFT

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Acknowledgement

Many of the novel operational concepts contained within this document were developed and refined for the NASA TIMED Mission. The STEREO Mission Operations Team would to thank the TIMED Mission Operations staff for their assistance in the development of the STEREO Concept of Operations.

1.0 General

1.1 Purpose

This purpose of this Concept of Operations (CONOPS) document is to describe, from a user's operational perspective, how the Mission Operations Team will conduct spacecraft on-orbit operations in response to the STEREO mission requirements.

1.2 Scope

This document focuses on those operations related to the spacecraft bus. Instrument (the spacecraft payload) operations are not specifically addressed due to the decoupled instrument approach. The Mission Operations Center (MOC) is emphasized while the other components of the ground system, like the Deep Space Network (DSN) and Science Operations Center (SOC) are only covered as far as their interface to the MOC is concerned.

1.3 Reference Documents

1. STEREO Requirements, A. Santo, October 8, 1998
2. MOC to Science Operations Center ICD, TBD
3. Program Service Level Agreement, January 29, 1999
4. Instrument ICDs, TBD
5. MOC Configuration Management Plan, TBD
6. Operational Constraints document, TBD
7. Operations Handbook, TBD
8. Contingency Plans, TBD
9. Early On-orbit Operations Plan, TBD

2.0 Operational Description

2.1 Mission

As part of NASA's Sun-Earth Connections program, the STEREO mission will provide a new perspective on solar eruptions and their consequences for Earth. To provide the images for a stereo reconstruction of solar eruptions, one spacecraft will lead the Earth in its orbit and one will lag. Each will carry a suite of instruments. When simultaneous telescopic images are combined with data from observatories on the ground or in low Earth orbit, the buildup of magnetic energy, lift off, and trajectory of Earthward-bound Coronal Mass Ejections (CMEs) can all be tracked in three dimensions. When a CME reaches Earth's orbit, magnetometers and plasma sensors on the STEREO spacecraft will sample the material and allow investigators to link the plasmas and magnetic fields unambiguously to their origins on the Sun.

The STEREO mission consists of two identical spacecraft in heliocentric elliptical orbits that are in the ecliptic plane at approximately 1 AU, one ahead of the Earth and the other behind it. The angular separation of the two spacecraft will be gradually increasing with a drift rate of 20°/year for the leading spacecraft and -28°/year for the lagging spacecraft.

The STEREO mission has a goal of two years with a possible extension of three years. There are four mission phases for the five years, which are determined by the angle between the two spacecraft (S/C) (a). Each angular separation phase has specific science objectives as listed below:

Phase	S/C Angular Separation	Science Objective
Launch to 400 days	$\alpha \leq 50°$	3D corona effects
400 to 800 days	$50° \leq \alpha \leq 100°$	CME physics
800 to 1100 days	$100° \leq \alpha \leq 200°$	Earth directed CMEs
After 1100 days	$\alpha > 180°$	Global solar evolution and space weather

2.2 Spacecraft Description

Each of the two STEREO spacecraft will be identical[1] with no redundancy. The spacecraft bus will be built by JHU/APL with NASA Goddard Space Flight Center (GSFC) procuring the instruments. The entire S/C will be integrated at JHU/APL.

The spacecraft bus consists of six operational subsystems supporting a payload suite of six instruments (Figure 2-1). The spacecraft bus is designed around an Integrated Electronics Module (IEM). The IEM is a single box that contains the Command & Data Handling (C&DH) and RF Communications subsystems on plug-in cards. The cards within the IEM communicate over a PCI parallel data bus. A MIL-STD-1553 bus is used for transferring command and telemetry data between the IEM, the instruments, the Guidance and Control (G&C) subsystem, and the Power subsystem. An RS-422 high-speed data bus is used for the science data interface between the IEM and the Solar Corona Imaging Package (SCIP) instrument.

The C&DH subsystem provides real-time, time tagged, macro, and autonomy command capabilities. It uses a Mongoose-V, 12 MHz, 32-bit processor that formats all telemetry into CCSDS compliant packets. A 7.5 Gbit RAM Solid State Recorder (SSR) is used for data storage of all science and engineering data. An Ultra Stable Oscillator (OSC) will be used for time reference. Time between the two spacecraft will be synchronized to within 0.1 seconds.

The RF Communications subsystem[2] will provide simultaneous X-Band (XB) uplink, downlink, and navigation data using one High Gain Antenna (HGA), two Medium Gain Antennas (MGA), and two Low Gain Antennas (LGA). The LGAs will provide communications from launch to 0.01 AU. The two MGAs are fanbeam antennas. The wide angle MGA will provide communications from 0.01 AU to 0.23 AU while the narrow angle MGA will be used for emergency communications when the S/C is in Safe Hold or Earth Acquisition modes. The HGA consists of a gimbaled, 1.1 meter, parabolic dish with a 115° gimbal travel. It will be used when the spacecraft range is greater than 0.23 AU. The HGA is steered autonomously.

There are two XB uplink rates, 125 bps for normal operations and 7 bps for emergency operations. Navigation data will be generated by an APL developed transceiver modified to obtain corrected two-way Doppler from uplink and downlink frequencies. The RF Communications subsystem is designed to use the DSN 34-meter Beam Wave Guide (BWG) antennas.

The G&C subsystem provides three-axis attitude control of the S/C and also controls the pointing of the HGA. Nominal orientation of the S/C will have the X-axis of the S/C pointed at the Sun

[1] The Energetic Particle Detector (EPD) alignment differs between leading and lagging spacecraft, hence the two S/C will not be truly identicl. Additionally, the SCIP occulation disks will be different between spacecraft.

[2] In order to accommodate changing requirements, the RF design for STEREO will most likely be changed during Phase A.

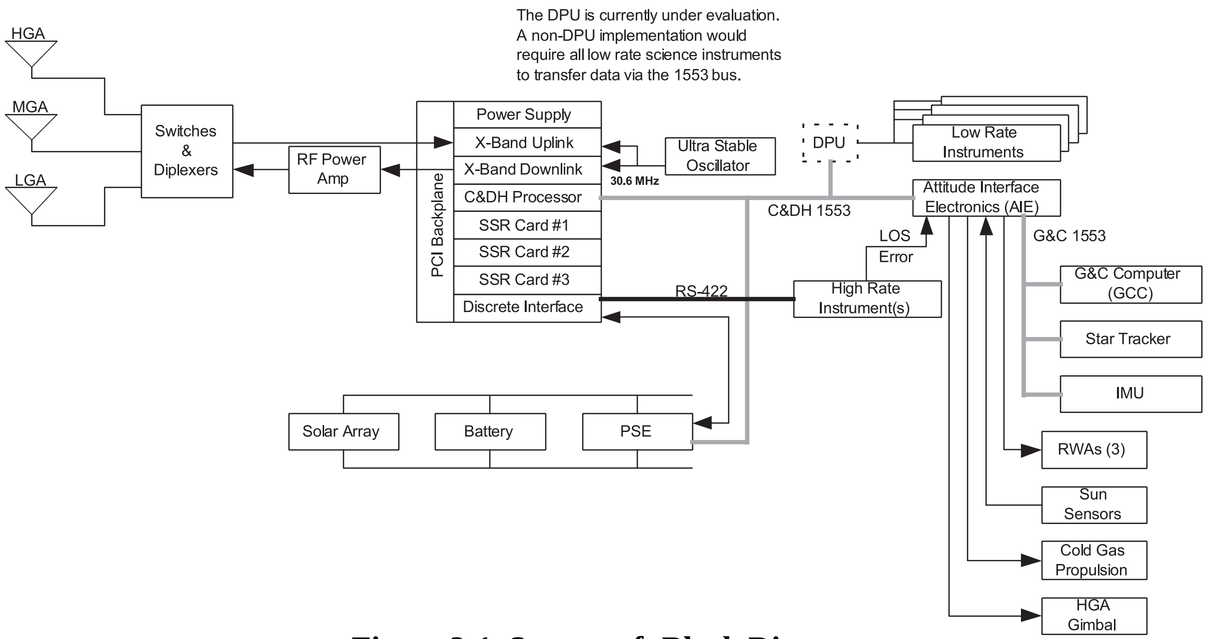

Figure 2-1 Spacecraft Block Diagram

within 0.1° (3 σ) and the HGA pointed at the Earth, also within 0.1° (3 σ). The G&C subsystem consists of the two processors, the Attitude Interface Electronics (AIE) and Attitude Flight Computer (AFC), three attitude sensors; an Inertial Measurement Unit (IMU), Star Tracker, and Digital Solar Aspect Detectors (DSAD), and two control components; Reaction Wheel Assemblies (RWA) and the Propulsion subsystem.

The AIE, using an RTX2010RH, 12 MHz processor, provides the interface between all attitude components and the C&DH subsystem. It also autonomously provides S/C attitude safing operations. A separate G&C MIL-STD-1553 bus provides communications between the AIE and the AFC, Star Tracker, and IMU. The AFC, using the same processor as the C&DH subsystem, implements the attitude control algorithm, thruster control, and HGA gimbal pointing.

The IMU provides S/C rate data using four hemispherical resonator gyro units. The Star Tracker autonomously identifies stars with brightness less than 7.5 Mv. There are five DSADs each with a ±640 field of view (FOV) to determine the Sun's location with an accuracy of 0.5°.

Three RWA provide pointing control. As S/C momentum builds in the RWAs it will be dumped autonomously by the G&C computer. This occurs, nominally, on every four day intervals, using thrusters in the Propulsion subsystem.

The Propulsion subsystem consists of a cold gas tank, two transducers, high-pressure latch valve, regulator, and four thrusters. The cold gas tank will contain approximately 1.7 kg (five liters) of GN2 at 5000 psia. This will be sufficient propellant to dump momentum for five years with a 10 percent leakage allowance.

The Power subsystem employs two fixed GaAs solar arrays (SA). Power is managed by a Peak Power Tracker (PPT) that will provide an unregulated 28V ±6V DC bus voltage. A 21 ampere-hour Super NiCd battery provides power from launch to SA deployment and for Low Voltage Sense (LVS) conditions.

The Thermal subsystem is a passive design using blankets, radiators, and thermostatically controlled heaters. All instruments will be thermally isolated from the S/C structure.

2.3 Spacecraft Operations

The spacecraft will be operated to collect data as the on board instrument suite observes the solar regions of scientific interest. The spacecraft bus is operated to support this data collection by providing nominal attitude, power, navigation data, thermal control, data storage, and rule-based autonomy. It is expected that the spacecraft will operate nearly autonomously, requiring only minimal ground support to uplink occasional command messages and to recover science and engineering data on a daily basis. Nominally, one contact, or track, with each spacecraft will be scheduled each day, for a duration of two or more hours. During the remainder of the time, the spacecraft will be on its own collecting data, measuring its own health and responding to any self-discovered anomalous operations. It will do this by carrying out a continuous performance assessment function that consists of observing its own telemetry and evaluating pre-stored autonomy rules related to performance and operation. The goal of the Mission Operations Team (MOT) will be to maintain a science data gathering capability though it is likely that some on board anomalies cannot be autonomously handled in a manner so as to preserve normal operations. In these cases the spacecraft may transition to a safe-hold or Earth acquisition mode (see Section 5.4) where science data collection is suspended and all non-essential instruments and subsystems are powered down.

The C&DH processor will receive ground-based command messages which provide initialization data, control instrument configurations, specify attitude configuration, allocate data storage reserves, and, in general, to 'orchestrate' the operation of the entire spacecraft. Command messages not specifically addressed to the C&DH processor will be conveyed to the addressed spacecraft bus subsystem and instrument destinations via a data bus. The C&DH subsystem will report in telemetry, the status of both the receipt (from the ground) and delivery (to the on board instrument or subsystem) of these commands.

State-of-health (engineering housekeeping) data throughout the spacecraft bus is sampled by the C&DH processor and is stored on the SSR. Science and engineering data produced by the instrument suite are also transferred to the SSR for storage. The SSR will hold about 7.5 Gbits of data which will be played back once per day. Real-time spacecraft engineering data will be interleaved (3%) with SSR playback data during a track. The amount of SSR data transmitted during a track will vary over the duration of the mission. Initially, the entire SSR will be played back each day. However, as the S/C to Earth range increases, the amount of SSR data played back will decrease. Eventually, during an eight-hour track, the entire SSR cannot be played back.

Spacecraft attitude will, nominally, be maintained with the X-axis at the Sun, with an accuracy of 0.1∞ (3 σ), and with the gimbaled HGA pointing at the Earth also with an accuracy of 0.1∞ (3 σ) continuously. This attitude will be controlled autonomously by the G&C subsystem. Attitude will be measured by star cameras, gyros, and DSADs, processed by the AFC and adjusted by controlling spacecraft momentum using the RWAs. Momentum build-up in the wheels will periodically be dumped using the cold gas thrusters. Attitude data will be generated and provided to the C&DH processor for broadcast to on board subsystems and instruments. The G&C subsystem produces, along with nominal engineering telemetry data, diagnostic data to be used for ground-based performance assessment. The contents of these buffers are transmitted to the MOC to support G&C subsystem performance assessment and possible anomaly investigations. If the spacecraft cannot maintain the preferred operational attitude, the G&C subsystem, via the AIE, will configure and maintain a safe-hold attitude with solar panels directed toward the Sun and the HGA pointed at the Earth with all non-essential loads powered down. Commands issued by the MOT will be required to transition out of this safe-hold mode.

Spacecraft power is provided by solar panels augmented by a storage battery. Typically, the battery will only be used during launch, anomalous operations and propulsion events. The solar panels are fixed along the Z-axis (Sun facing). A Peak Power Tracking feature controlled by a software algorithm resident in the C&DH processor maintains maximum power subsystem efficiency.

The C&DH subsystem continuously monitors telemetry parameters for violations of established operating rules. These rules are defined and uploaded by the MOT. Rule violations invoke command sequences that tend to overcome the cause of the violating condition. These autonomous operations attempt to maintain an operational spacecraft, but there maybe anomaly situations that the S/C autonomy rules do not cover. In these instances, the spacecraft will transition to safe-hold mode or earth-acquisition mode and await ground command response.

As part of the normally generated engineering telemetry, the spacecraft preserves a record of all commands executed on board. Included are real-time, time tagged, macro, and autonomous command execution. Such data is necessary to assess operational performance of the spacecraft bus.

2.3.1 Command Uplink

The spacecraft C&DH subsystem receives command uplinks from the ground system that may either be addressed to the Uplink Critical Command Decoder or the C&DH processor. Command packets are formatted into command transfer frames by the MOC. A packet, of variable length, may be embedded within a single transfer frame or may span over several transfer frames. The packet is addressed to a particular spacecraft subsystem or instrument and all packets contained within a transfer frame must be addressed to the same subsystem or instrument. The C&DH processor ingests and assembles the complete packet, then routes it, via the PCI or MIL-STD-1553 bus (depending on the addressed subsystem or instrument), to its destination. If the received packet is incomplete or otherwise unacceptable, based on error detection criteria, the packet is rejected in its entirety and a status message is transmitted to the ground system. However, the C&DH processor does not check the contents of the command packet. Once the designated subsystem or instrument has received a packet, it is the responsibility of that subsystem or instrument to evaluate the packet content for acceptability. The report of this evaluation must be conveyed via the engineering telemetry produced by that subsystem or instrument.

Besides the direct delivery method of commanding described above, the Uplink Critical Command Decoder may command certain spacecraft configuration states. This unit, which ‘parallels’ the C&DH processor, may issue only configuration commands which control the power switching relay states. These critical (relay) commands are formatted in packets, one command per packet, by the MOC, and then uplinked, in real-time to the spacecraft Uplink Critical Command Decoder. These commands are executed as they are received in real-time since there is no on board storage of these commands.

The Uplink Critical Command Decoder also handles all relay (power switching) commands and provides an emergency capability to configure the spacecraft (i.e., to power on and off instruments and subsystems). The normal method of commanding is through the C&DH processor. However, the C&DH processor may not always be powered on, hence the need for an alternate emergency command capability.

The S/C can handle two uplinks rates, 125 and 7 bps. Normally, 125 bps will be used. The lower 7 bps rate is for communications during anomalous operations.

2.3.2 Telemetry Downlink

There are three downlink rates available on the S/C; high-rate science, low-rate science, and low-rate engineering. Normally, the high-rate science downlink rate will be used. This rate employs the HGA with Reed-Solomon (RS) +6:1 convolutional coding. Real-time science and engineering telemetry has priority. That is, if real-time science and engineering data are selected for downlink, then any data generated in real-time by either the spacecraft bus or instruments is formatted into transfer frames and downlinked immediately. Typically this rate will be used to play back the SSR with three percent real-time data interleaved.

The low-rate science downlink rate uses RS +2:1 convolutional coding. This rate will only be used if the scheduled DSN station cannot support the RS +6:1 convolutional coding. Real-time science and engineering data as well as SSR playback data can be transmitted at this rate. Space weather data (broadcast mode) will also be transmitted at this rate at all times when the spacecraft is not communicating with DSN.

The low-rate engineering downlink rate does not use any encoding. It will only be for anomalous operations.

2.3.3. Early Operations

Early spacecraft operations is treated as a separately because of its criticality and singular use. The Early Operations phase extends from launch vehicle separation to the declaration, by the Mission Planning Team, that the spacecraft bus and all instruments are capable of supporting the mission objectives. This phase encompasses launch load preparation through on-orbit checkout and evaluation. The launch load consists of a command sequence that will control critical spacecraft bus operations immediately after separation from the boost motor. These commands will provide:

- Deployment of solar panels
- Powering on the IEM and other bus components
- Initiation of safe-hold mode attitude capture

The S/C separation sequence triggers the pre-stored launch load command sequence in the C&DH subsystem. This sequence will sustain spacecraft operations until the first scheduled DSN track occurs. The MOT, upon evaluation of the performance of the spacecraft bus at that time, may choose to alter the planned operational sequence or may elect to continue with the stored launch load sequence until the next scheduled track.

The primary activity during this Early Operations phase will be to checkout the subsystems and instruments on the S/C. The STEREO MOT will depart from the normal operations staffing plans to provide a more or less continuous 24-hour/day support. For the first few days, more than one DSN track per day will be requested. The Early Operations phase will be supported by combined MOT, SBET, and instrument teams located at the MOC and the SOC. Launch operations teams may also be utilized as required.

2.4 Instrument Operations

During Normal Operations, all instruments will be powered and time tagged command capability will be enabled. For this mission, all instrument operations will be decoupled from the spacecraft bus operations (per Reference (1)). The goal is to support a concept of decoupled operations, which reduces system complexity and cost. With only a few exceptions, the spacecraft bus and the instruments will be operated independently of each other (Section 2.5). The same can be said about the ground elements (the SOC and the MOC). This decoupling of instrument operations concept greatly simplifies the operations process, which traditionally requires these functions to be merged in a complex manner.

The SOC is responsible for the following operational tasks for all instruments:

- Planning, scheduling, and generating instrument commands
- Instrument health
- Calibration
- Synchronization of instrument operations between S/C

Instrument command loads will be assembled as packets and transferred to the MOC prior to a scheduled contact, or track. Separate command messages are required for each S/C. Included, as part of the command packet transfer to the MOC, will be certain identifying data to be used by the MOC to verify that an authorized source has generated and transferred the data. The SOC will attach data that specify both the earliest and latest times that the attached command packet may be uplinked to the instrument. The MOC will be responsible for the delivery of the content of the packet(s) to the addressed instrument but assumes no responsibility regarding the actual commands. On the S/C, a shared MIL-STD-1553 data bus provides all data interfaces between the spacecraft and the instruments . The spacecraft acts as the bus controller, and each instrument is a remote terminal. The C&DH subsystem will report in telemetry, the status of both the receipt (from the ground) and delivery (to the on board instrument or subsystem) of these commands. The SOC will be responsible for the verification and validation of instrument response based on the uplinked command load.

Due to the relatively low command uplink rate, instrument teams should design their instrument to require a small number of commands per day. Nominally, an hour of instrument command uplink time for each track has been set. This translates into approximately 450 kbits of instrument command data for all instruments per track.

The spacecraft will support storage of command packets for distribution to the instruments at a later time. The aggregate size of memory available to all instruments for stored commands is enough to hold approximately 400 commands. Stored command packets may be individually time tagged with one second precision, or may be part of a macro sequence.

An unpacketized broadcast message will be distributed to all instruments once per second.

This message will contain:

- Time
- Warning flags:
  - Sun keep-in violation
  - Thruster firing

  - Instrument power off
  - Indication that the next housekeeping data set will be downlinked or recorded
- Spacecraft housekeeping data required for instruments

The spacecraft will poll the instruments for data via the MIL-STD-1553 bus (and science packets from the dedicated RS-422 high speed link for the SCIP only) according to a fixed schedule. It will either downlink the data in real-time or record it on the SSR.

The spacecraft will not process instrument data before recording or downlink; any processing or data compression is the responsibility of the instruments. The instruments will have no direct access to the SSR and will not be able to retrieve data stored on it.

The instruments will generate each science data packet according to the full CCSDS telemetry packet format, including primary and secondary headers, checksums, etc. The maximum aggregate data collection rate for science packets from all instruments will be 408 kbps.

Housekeeping data from each instrument will be collected every second. The spacecraft will perform very rudimentary monitoring of this data strictly for fault protection. For example, one bit in the packet will be designated as a request by the instrument for the spacecraft to turn off its power. Other than this monitoring, the instruments cannot depend on the spacecraft to perform any processing of their housekeeping data. Each instrument will include housekeeping data in its science data packets if needed for science evaluation.

A small amount of unpacketized "space weather" data from each instrument will be collected every second.

2.5 Data Flow

Figure 2-2 illustrates conceptual flow of command and telemetry data between the ground-based spacecraft bus and instrument operations elements and the on-orbit STEREO spacecraft. The ‘outer-loop’ depicts instrument operations. Using a decoupled instrument operations approach, all instruments will be operated by the instrument operations team at the Science Operations Center (SOC). In Figure 2-2, begin at the SOC Planning on the far right, where instrument commands are produced. These command messages, which will be packetized along with some additional information needed by the MOC, are transmitted to the MOC via the Internet. At the MOC (MOC Authorize and Route) there is some checking performed, then these commands are queued for eventual uplink to the instrument. Along with the command packets, the SOC appends timing information which indicates the time span (earliest and latest times) over which the command packet may be uplinked to the instrument. Real-time command packets, when uplinked to the spacecraft, are immediately routed by the spacecraft bus C&DH processor (the C&DH Routing Service) to the appropriate instrument and time tagged and macro command packets are stored in the instrument’s allocated storage locations in the C&DH processor. Conceptually, the command packet goes ‘directly’ from the SOC to the instrument, since the MOC, ground station and spacecraft bus are merely the delivery system. This delivery system notifies the SOC of the delivery status of the command message.

Whereas the SOC produce instrument commands, the MOC produces spacecraft bus commands. This is depicted in the ‘inner-loop’ on the Data Flow diagram (Figure 2-2). Starting at the MOC

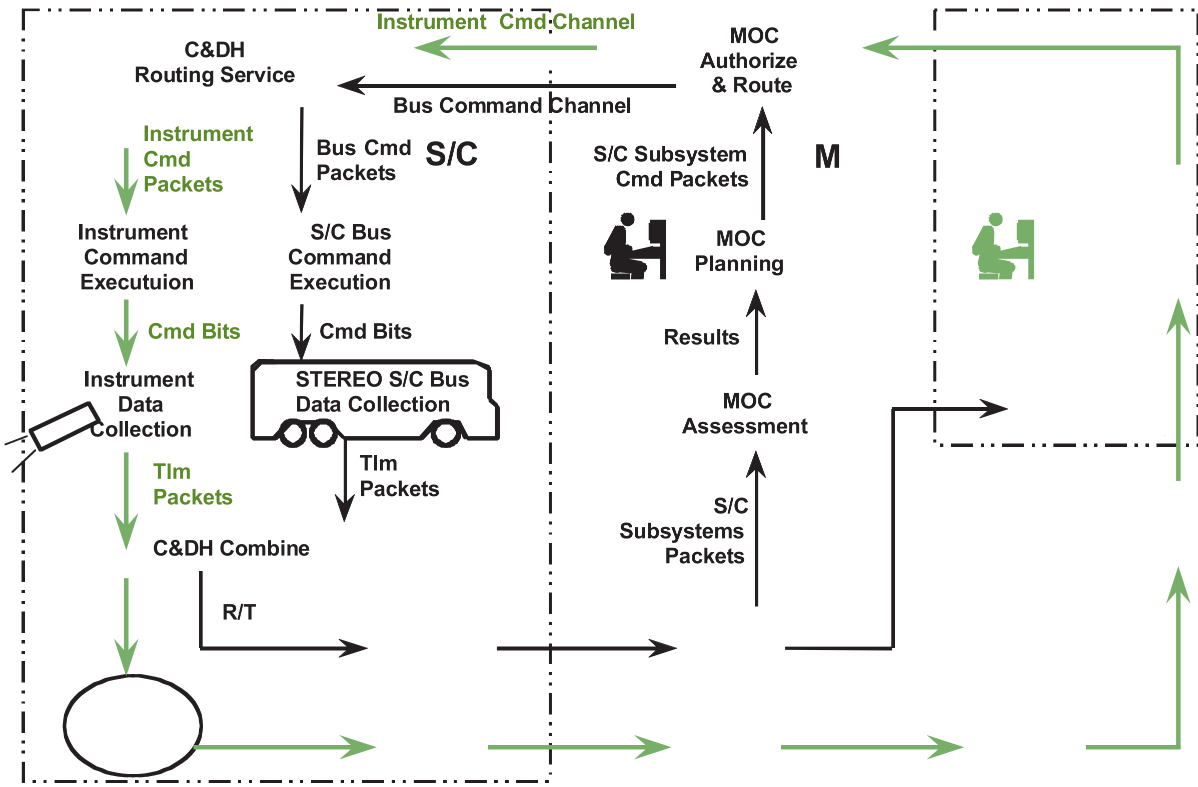

Figure 2-2 STEREO Mission Data Flow

Planning process, the Mission Operations Team (MOT) prepares command messages to the spacecraft bus to operate it during the next day. These command messages are queued for uplink (MOC Authorize and Route) just like the instrument commands, only they go to a different destination (via the C&DH Routing Service). The C&DH processor immediately routs real-time commands, to the appropriate spacecraft subsystem and time tagged and macro commands are stored in the C&DH processor. The MOC receives delivery status of the command packets just as the SOC does.

Once these command messages have been executed (Instrument Command Execution and S/C Bus Command Execution) on the spacecraft, they integrate its operation. The instruments produce science and engineering data (Instrument Data Collection) in response to the uplinked command messages. The data produced by the instruments is sent to the spacecraft data system in the form of CCSDS telemetry packets. Similarly, engineering data produced by the spacecraft bus is also formatted into CCSDS packets. The packets, produced by the instruments and the spacecraft bus and conveyed to the spacecraft data system (C&DH Combine), are stored on the SSR within the spacecraft data system (C&DH Recording). During a track with the S/C, the contents of the SSR are transmitted to the MOC (C&DH Frame Packaging).

On the ground (Ground System Telemetry Routing), real-time data is forwarded to the MOC and to the STEREO Data Server (SDS), while all recorded data is sent to the server facility (SDS Clean and Merge). All instrument data will be sent to the SOC for processing and analysis. The cycle repeats, with the SOC preparing instrument commands for still another day in space. Spacecraft bus data is routed to the MOC (MOC Assessment) where an assessment function is performed. The MOC spacecraft bus planning process then repeats.

Of significance is that the instruments and spacecraft bus are operated (almost) entirely independent of each other. The same can be said about the ground elements (the SOC and the MOC). This decoupling of instrument operations concept greatly simplifies the operations process, which traditionally requires these functions to be merged in a complicated manner.

2.5.1 Command Data Flow

The MOC produces spacecraft bus commands, processes SOC-generated instrument commands and provides a command gateway for all commands to the spacecraft. All instrument command messages from the SOC, along with some additional identifying and timing data are sent to the MOC (Figure 2-3). At the MOC, the FTP Server and Authenticator validates the proper sender [the SOC provides an encrypted source identifier and an application command packet (destination instrument) identifier]. An authentication receipt is returned to the SOC.

Once a command has authenticated, it enters a Staging Queue. There is one such queue for each instrument on each S/C. Appended to the command message (the command packet and header) is a start and expiration time specification. These represent the earliest and latest times that the command

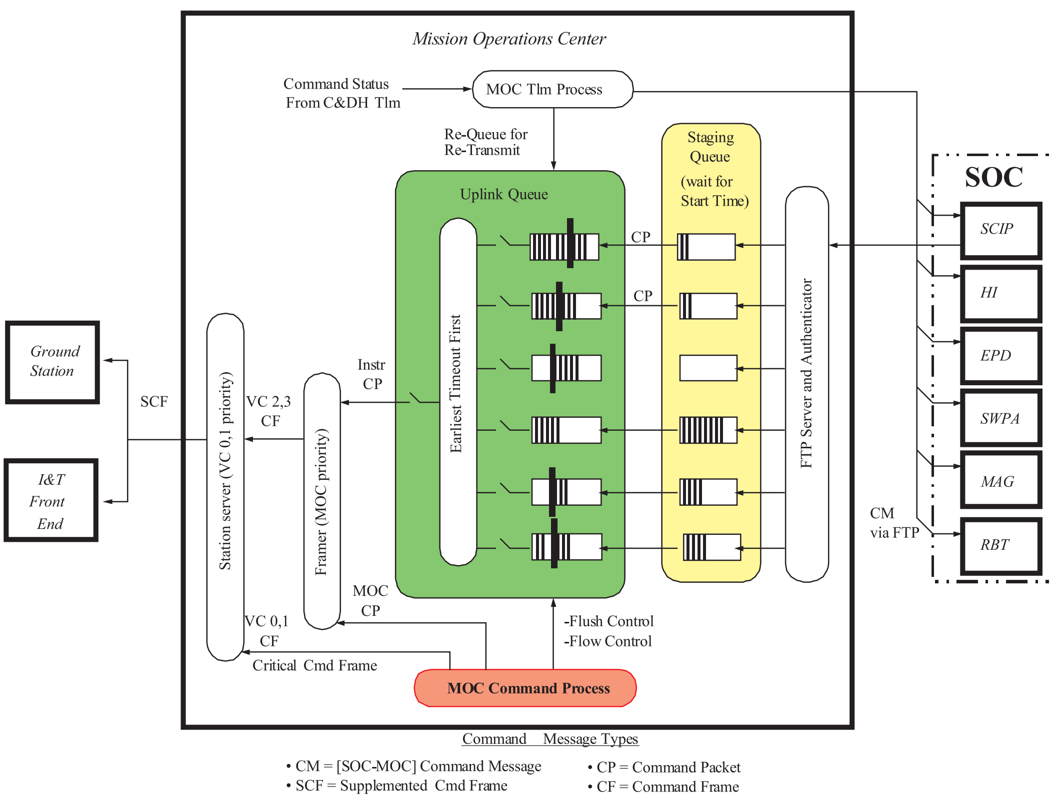

Figure 2-3
Command Data Flow

packet may be uploaded to the instrument as specified by the SOC. Once past the start time, the command packet is transferred to the Uplink Queue (again there is such a queue for each instrument on each S/C). Command packets in the Uplink Queue are ordered by expiration date, with those packets marked by the earliest expiration date ordered so as to be uplinked first. The MOT may examine the contents of the Uplink Queue to determine the number and size of the packets stored there. All stored commands will be uplinked beginning at the next ground station track, as long as time permits (the track is of sufficient duration) unless the MOT places a ‘grocery bar’ separating command packets within the queue. All commands to the left of the bar are uplinked, those to the right of the bar are prevented from being uplinked. This mechanism affords the MOT some degree of control of the uplink command packet traffic to the spacecraft.

The switch at the output (left side) of the Uplink Queue will either enable, when closed, or disable, when opened, instrument packet command flow to the spacecraft. The queues can be flushed by MOT control. If the SOC desires to replace the content of an instrument uplink queue, either entirely or in part, the entire queue is flushed and must be reloaded in its entirety. The MOC will issue notification (receipt) to the SOC of either an uplinked packet or a flushed queue.

Commands prepared for spacecraft bus operation are merged with instrument commands. Normal C&DH command packets are merged at the Framer. Here, spacecraft bus commands have priority, i.e., spacecraft bus commands are uploaded first. Commands destined to the spacecraft bus Uplink Critical Command Decoder (Virtual Channel 0 or 1) are merged at the Station Server with Uplink Critical Command Decoder command packets assigned a higher priority than spacecraft bus C&DH processor or instrument command packets (Virtual Channel 2 or 3).

The status of command packet delivery to the C&DH processor is provided via C&DH telemetry. Additional status of command packet delivery to an instrument or subsystem is also provided via C&DH telemetry. This status is forwarded to the SOC for instrument command packet delivery as a return receipt. Thus the SOC are informed of the delivery, but not the verification of actual command content. This must be provided by instrument telemetry, which can be processed only by the SOC.

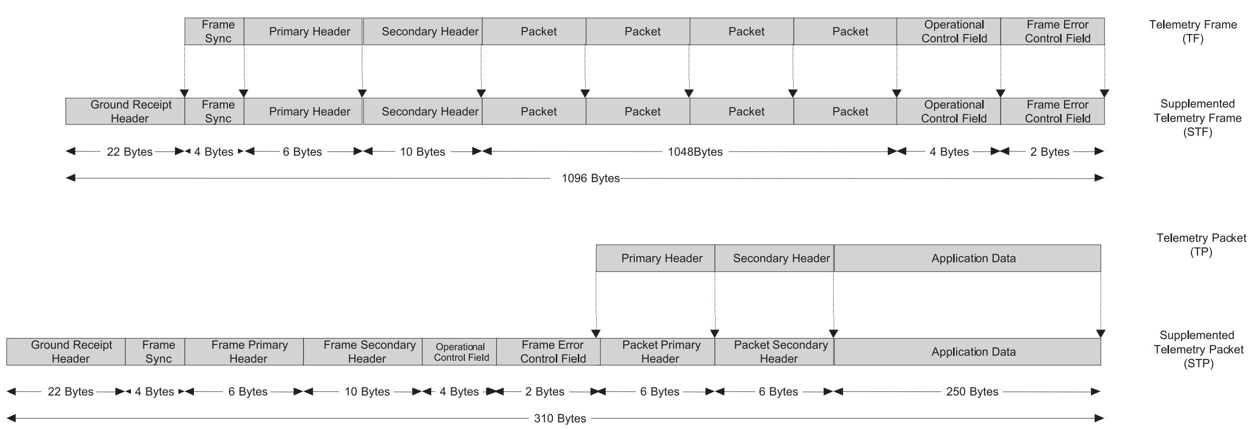

Figure 2-4 Telemetry Data Formats

The Integration and Test (I&T) Front-End, which is only utilized during spacecraft ground-based testing, is shown in the Figure 2-3. This may be utilized to provide MOC-generated command data to the spacecraft simulator during the on-orbit phase.

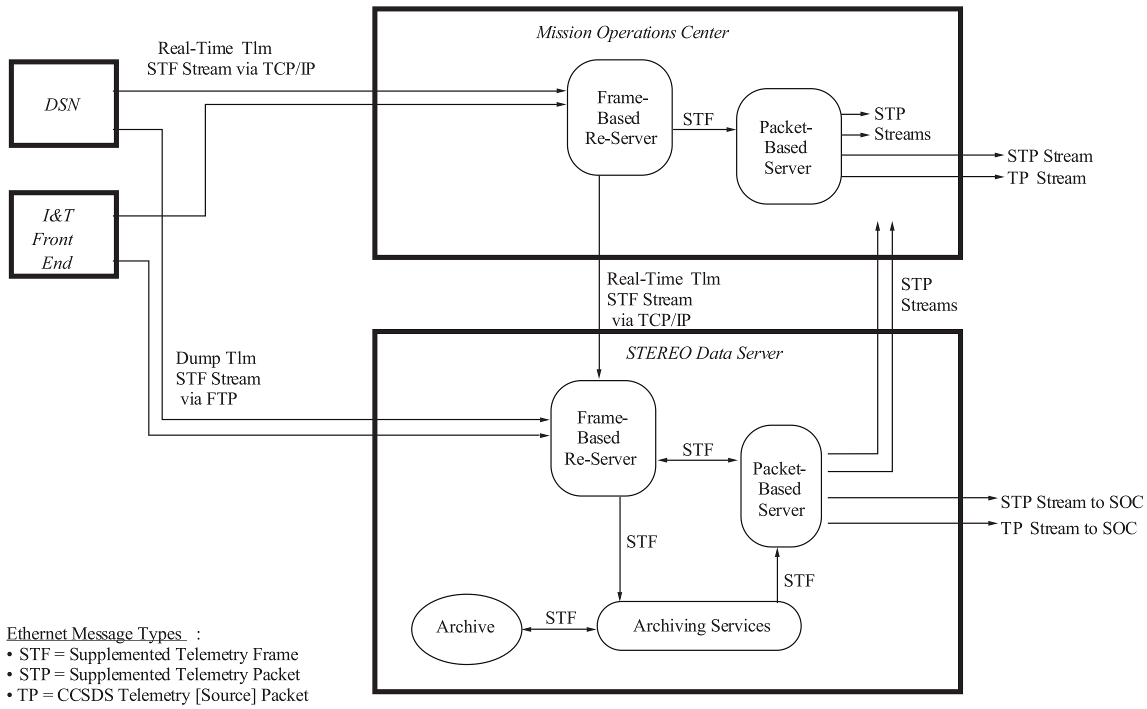

Figure 2-5 Telemetry Data Flow

2.5.2 Telemetry Data Flow

The C&DH processor generates CCSDS formatted Telemetry Frames (TF) (Figure 2-4). A ground receipt header, containing the ground receipt time, RS encoding type, and other necessary information, is added to each TF by DSN and modified by the MOC. A Supplemented Telemetry Frame (STF) is created by the addition of the ground receipt header to the TF. The STF are the form of data that is flowing in the MOC and is stored in the SDS.

Each S/C bus and instrument generates CCSDS formatted Telemetry Packets (TP). With the addition of the ground receipt header and TF header data to the TP forms the Supplemented Telemetry Packet (STP) (see Figure 2-4).

Figure 2-5 illustrates the flow of real-time and SSR playback telemetry data between DSN and MOC and SDS. Real-time telemetry data is flowed from DSN to the MOC as STF. Playback telemetry data is flowed from DSN to the SDS, again as STF. In both real-time and playback data flows, the received packets are re-served to a packet-based server where telemetry packets are extracted and output as STP and as CCSDS telemetry source (as the data was generated by the spacecraft) packets (TP). In both cases, packet streams, a flow of packets placed end-to-end in time order as they were received, are produced. The MOC provides the real-time telemetry it receives to the SDS for storage. Telemetry packets stored by the SDS, including the spacecraft playback bus engineering telemetry, is provided to the MOC. For the SOC, real-time telemetry are 'streamed' while playback data are file transferred.

The I&T front-end, which is only utilized during spacecraft ground-based testing, is shown also. This may be utilized to provide spacecraft simulator generated data to the MOC and SDS during the on-orbit phase.

3.0 Operational Requirements

The operational requirements for the Mission Operations System (MOS), as delineated by Reference (1), are as follows:

3.1 The MOS must be designed to support launch, early orbit checkout, and the first 800 days of science life mission phases.

3.2 Instrument operations will be decoupled from the S/C bus operations, i.e., instrument commanding and assessment will be done by the SOC.

3.3 There will be one track/day/vehicle.

3.4 The MOS must support operations for two concurrent S/C.

3.5 The MOS must support near real-time, bent-pipe instrument commanding and provide bent-pipe telemetry to SOC for each track.

3.6 The MOS must support wheel desaturation maneuvers.

3.7 Playback SSR data on each track.

3.8 Do not overwrite SSR data.

3.9 Maintain the Mission Elapsed Time (MET) correlation to Coordinated Universal Time (UTC) within 0.5 seconds and provide correlation data to the SOC.

3.10 Ground System Requirements

3.10.1 Provide a near real-time and time tagged commanding interface to the S/C for the SOC up to 1 hour (~450 kbits) of instrument commands/track.

3.10.2 Provide a telemetry interface for a near real-time access from a file-based system for the following: housekeeping, science, attitude history, time correlation, real-time broadcast, and navigation data.

3.10.3 Provide C&DH command storage space of 400 command packets/instrument for instrument time tagged and macro commands.

3.10.4 Provide the capability to identify dropped packets from an SSR playback within 1 hour of receipt.

3.10.5 Create a real-time S/C simulator after launch by assembling C&DH and G&C brassboards to G&C environmental simulator.

4.0 Mission Operations System Overview

The STEREO MOS consists of the two spacecraft, DSN ground stations, MOC, and SOC (Figure 4-1) and their respective operational teams. The STEREO spacecrafts will be operated by JHU/APL utilizing DSN for vehicle communications. The spacecraft bus and the instrument suite will be operated in a decoupled fashion; the MOC will provide all support of spacecraft bus operations, the SOC will operate all instruments on both S/C although communication between the SOC and the spacecraft will necessarily flow through the MOC. All spacecraft servicing, including

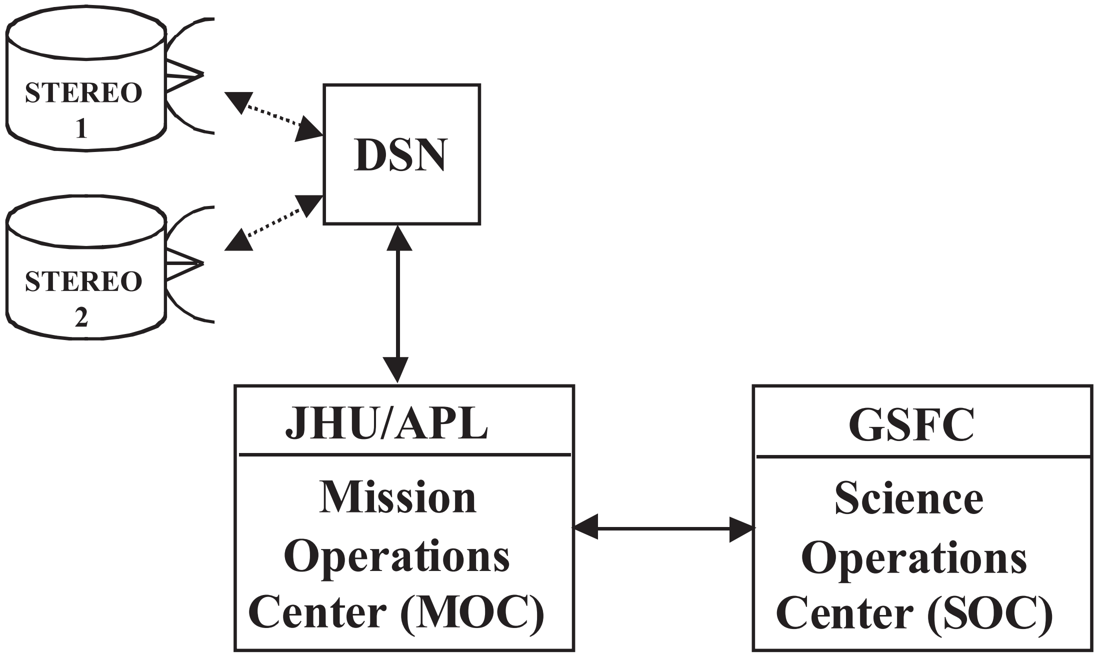

Figure 4-1 STEREO MOS Architecture

commanding and data recovery will occur during a single (nominal) ground track each day. This track will extend over a four to eight hour window, depending on the vehicle range from Earth. Spacecraft command messages will be uploaded and real-time engineering data will be received and evaluated to assess spacecraft health. The SSR will be played back on each track and all science data flowed to the SOC in near real-time.

A descriptive overview of the spacecraft and its operation are discussed in Sections 2.2, 2.3, and 2.4.

4.1 Mission Operations Center (MOC)

The MOC has the primary responsibility of management of the spacecraft bus including the development of command messages and the uplink to the spacecraft by way of DSN. Recovery of spacecraft bus engineering (state-of-health) telemetry and the performance analysis based on this telemetry is also performed at the MOC. The MOC receives instrument command messages (packets) from the SOC and, after verification that the SOC has prepared the commands, queues these for uplink to the spacecraft based on start and expiration times appended to the command messages by the SOC.

The MOC is located at JHU/APL in Laurel, MD. It is operated by the MOT and is nominally staffed during business hours, five days per week.

Figure 4-2 illustrates the MOC and includes interfaces to other MOS elements. NASCOM communication lines connect the MOC to DSN. Communications to the SOC are via the Internet,

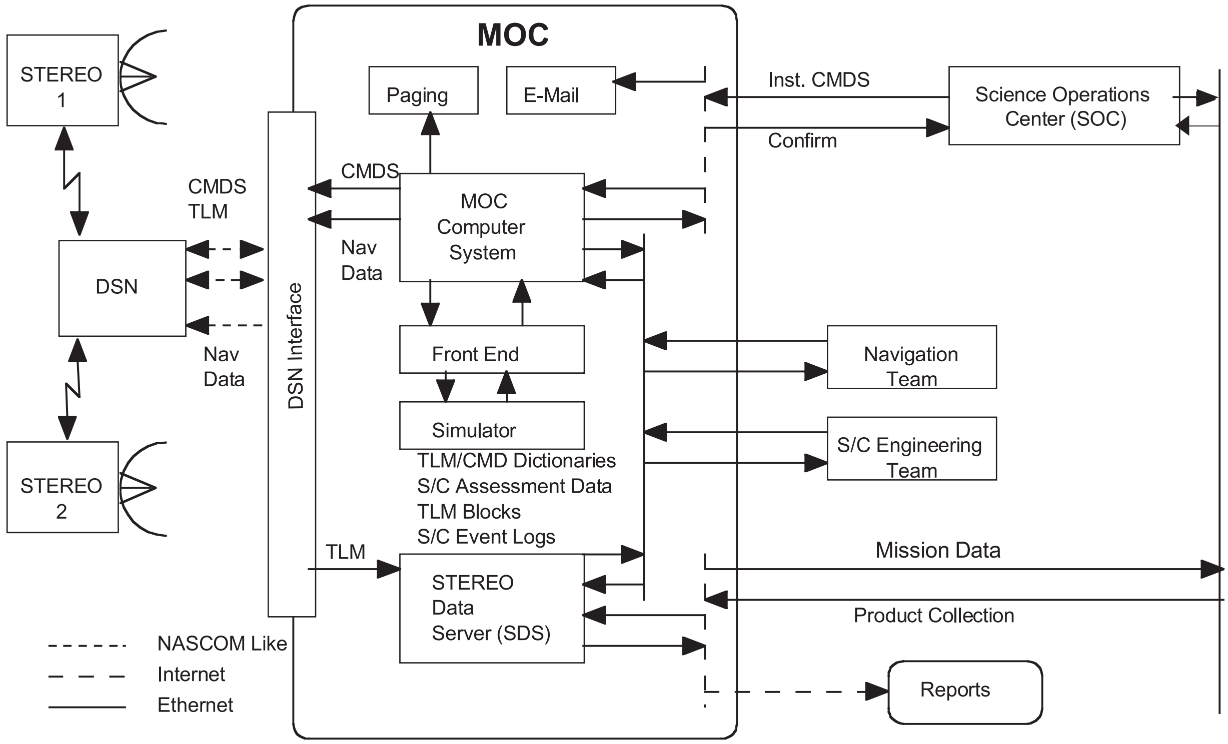

Figure 4-2 MOC Interfaces

with a modem backup. Within the MOC are workstations to support spacecraft commanding, spacecraft bus monitoring and analysis, primary and backup databases, and user files. The primary and backup command workstations are isolated from the rest of the MOC by a router/firewall. Commands to the spacecraft may *only* be issued from these workstations. Real-time telemetry is flowed through the firewall to the remaining workstations. Received telemetry (both real-time and SSR playback retrieved from the SDS) may be processed and displayed on these workstations. Main data paths are at least 100 Mbps Ethernet, with distribution within the MOC to some workstations and printers on 10 Mbps Ethernet. Unix based workstations are provided for MOT and spacecraft bus engineering team use. The SDS and the Spacecraft Simulator are also contained in the MOC.

4.1.1 STEREO Data Server

The SDS is located at JHU/APL in the MOC and functions as the central repository of spacecraft bus engineering telemetry, command files, mission planning data, ground system telemetry and status, and external correlative measurement data for the MOC. The SDS may be accessed, continuously (24 hours/day), via standard Ethernet/Internet-type communication lines.

A detailed diagram showing the data flow in and out of the SDS is illustrated in Figure 4-3. The SDS receives raw spacecraft data (SSR playback science and engineering) directly from the DSN (or a simulator). The MOC may transfer real-time telemetry and command data to the SDS. These data enter the SDS at the Telemetry/Command (TLM/CMD) Ingest process. A tape backup is

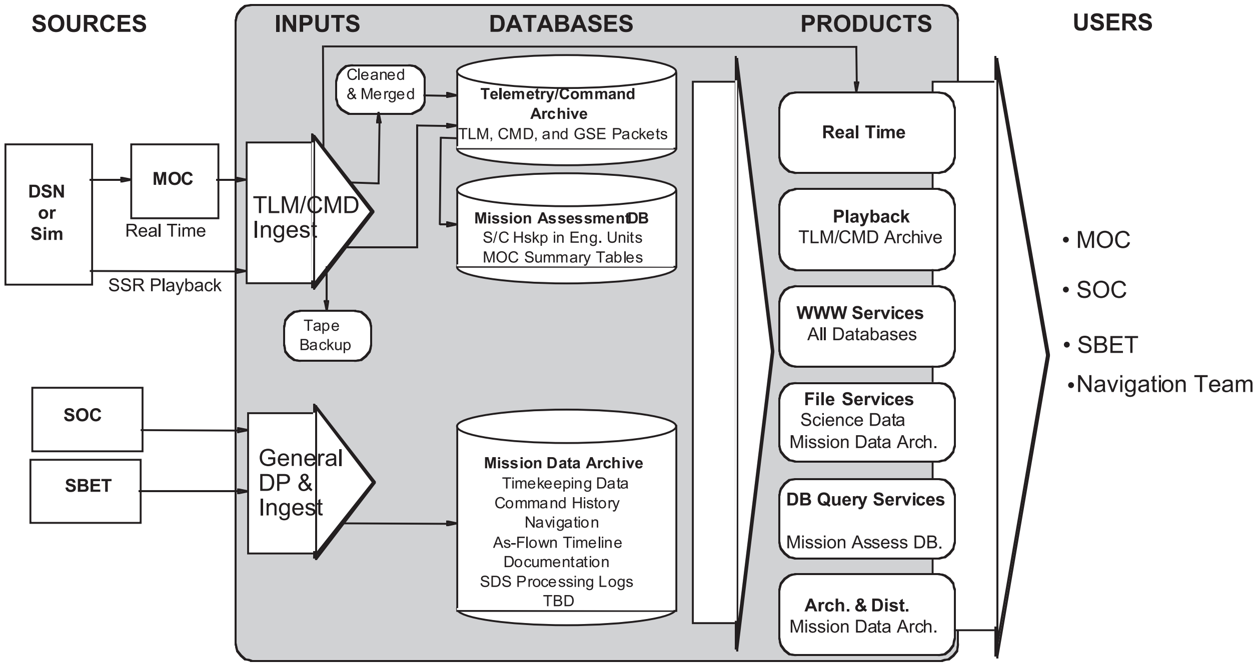

Figure 4-3 STEREO Data Server and Interfaces

provided here. This process may also serve real-time data (science and engineering telemetry) to users. Ingested data are cleaned and merged, then stored in the Telemetry/Command Archive database as packets. Engineering telemetry and command data, as well as ground system, data are stored here. Some data are stored in a Mission Assessment database (DB). Included are converted (to engineering units) spacecraft bus engineering telemetry and MOC processed data. The Mission Data Archive database including timekeeping data, navigation and orbit data, timelines, processing logs, command history, and documentation. These are inputted and processed by the General DP (Data Processing) and Ingest function.

The databases maintain the data products required by the users. These products, as shown, include real-time engineering telemetry, playback engineering telemetry and command files, World Wide Web (WWW) access to all databases, files services to access archived data, mission assessment database, and archival and distribution services. The users will include the SOC, MOC, and spacecraft bus engineering team.

On a daily basis, the SDS stores all command packets produced by the SOC and the MOC as well as all spacecraft engineering data and ground system engineering data. The real-time data acquired by the MOC is flowed to the SDS as it is received (the MOC also retains this data to support real-time operations and assessment). The SOC may access this real-time data from the SDS, with only a short time delay incurred. The SSR playback data will be transferred to the SDS and will be distributed to both the MOC (spacecraft bus engineering data) and the SOC (instrument science and engineering data). Spacecraft telemetry data are referenced (stored) by virtual channel number at the SDS and the data are accessed as ‘streams’ of data (that is the unprocessed telemetry is flowed in time order from the SDS to the user). The user must accept all data of the specified virtual channel and over the time interval specified. In the case of real-time data transfer, this ‘spigot’ is either open or closed. When open, all real-time data is flowed to the user as the SDS ingests the data.

4.1.2 Spacecraft Simulator

A S/C Simulator will provide real-time verification of command sequences, software loads, and expected telemetry. It also will be used for training new Mission Operations staff.

It will comprised of equipment used during the I&T of the S/C.

4.2 Deep Space Network (DSN)

The DSN will be used to provide communications to both spacecraft from launch to end of life (EOL). The use of all three DSN antenna facilities, Goldstone, Madrid, and Canberra, are required to determine the elevation component for the navigation of each spacecraft. Nominally, one track per day per spacecraft will be conducted using the 34-meter BWG antennas.

The MOC is connected to the DSN via NASCOM links. Orbit data for each spacecraft will be provided periodically to DSN.

4.3 Science Operations Center

The SOC has the responsibility for the operation and assessment of all instruments on the spacecraft. This includes the following instrument operational tasks:

- Planning, scheduling, and generating instrument commands
- Instrument health
- Calibration
- Synchronization of instrument operations between S/C

Instrument command loads will be assembled as packets and transferred to the MOC prior to a scheduled spacecraft track. Separate command messages are required for each S/C. Included, as part of the command packet transfer to the MOC, will be certain identifying data to be used by the MOC to verify that an authorized source has generated and transferred the data. The SOC will attach data that specify both the earliest and latest times that the attached command packet may be uplinked to the instrument. The SOC will be responsible for the verification and validation of instrument response based on the uplinked command load. The MOC will be responsible for the delivery of the content of the packets to the addressed instrument but assumes no responsibility regarding the actual commands.

Similarly, the processing of science and engineering data pertaining to all instruments is the responsibility of the SOC. Recorded science and engineering data will be available to the SOC via the SDS.

The SOC also has the responsibility for archiving all science data for the duration of the mission for both S/C. The MOC will provide, via the SDS, the following data products in file format to the SOC:

- Science
- Real-time space weather
- S/C bus and instrument engineering

- Attitude history
- Time correlation
- Navigation

The MOC is connected to the SOC via a commercial Internet connection with a modem backup and will utilize standard TCP/IP protocols. The SOC is located at the GSFC in Greenbelt, MD.

Real-time command and telemetry monitoring operations are expected to be available although such operations are considered only as contingency operations (including the possibility of initial early on-orbit operations).

The SOC will be provided ground system planning information by the MOT. Included are the schedules for DSN tracks schedules, track plans, orbit data, S/C bus health, etc. All such information will be provided via the SDS.

4.4 Mission Operations Team

The following four teams will work to support the STEREO mission.

- Mission Planning Team (MPT)
- APL Mission Operations Team (MOT)
- DSN
- Science Operations Team

This section will only discuss the APL MOT.

The MOC is staffed and operated principally by the MOT. The Spacecraft Bus Engineering Team (SBET) and instrument teams (when the Test SOC is installed) will provide staffing to support specific operations.

The MOT is responsible for all spacecraft and commanding, the recovery of all spacecraft telemetry, the assessment of spacecraft bus performance, and the control, monitor and performance assessment of all ground components necessary to support these functions. During the Normal Operations mission phase, the MOT staff will be comprised of the following:

- Flight Operations Manager
- Spacecraft Specialists (two/vehicle)
- DSN Scheduler
- System Maintenance Engineer

The *Flight Operations Manager* is responsible for the following functions:

- Overall conduct of operations
- Providing a central point of contact between the MOT and the external MOS
- Manage any adjustment to the operational schedules
- Interface between science personnel and the MOC
- Occupy the position of a DSN Scheduler, when necessary

The *Spacecraft Specialists* are responsible for the following functions:

- Spacecraft bus operational planning and command generation
- On-line spacecraft control and readiness tests
- Spacecraft bus and ground system performance assessment
- Lead spacecraft and ground system troubleshooting activities
- Operation of the S/C Simulator

The *DSN Scheduler* is responsible for the following:

- Advance, weekly, and daily scheduling of DSN antennas for both S/C
- DSN liaison

The *System Maintenance Engineer* is responsible for the following:

- Normal maintenance and calibration of the MOC components
- MOC communication connections
- MOC software upgrades

Each Spacecraft Specialist will have detailed operational knowledge of the commands, telemetry, and constraints of the each S/C. This will be acquired by assisting the SBET and I&T teams with S/C integration and test. Each Spacecraft Specialist will be able to carry out all on-orbit operational activities for each S/C, i.e., planning, control, and assessment.

During the Early Operations mission phase, the MOC will be staffed 24 hours/day and seven days/week. During the Normal Operations mission phase, the MOT staff will transition to business hours, five days/week. This will require the validation of many automated MOC procedures and autonomy rules on the S/C. Occasional off-business hours scheduling is likely to occur during some special operations including contingency activities.

4.4.1 Spacecraft Bus Engineering Team

Although the MOT will be entirely capable of operating the spacecraft bus and detecting and responding to anomalies, the Spacecraft Bus Engineering Team (SBET) is considered an essential and integral adjunct. The SBET consists of the spacecraft subsystem development teams, along with the MOT. Together, they maintain the complete technical knowledge base regarding the operation and performance of the spacecraft bus. During the subsystem level testing and the follow-on spacecraft bus I&T, the MOT, working side-by-side with the SBET, will acquire the knowledge necessary to operate the spacecraft bus on-orbit.

After launch, when operational anomalies are uncovered by the MOT, an immediate assessment will be made to ascertain the ability of the MOT, with the accrued knowledge and existing contingency procedures, to correct the anomalous operation within a reasonable time frame. If the anomaly is not clearly understood or if the recovery action is uncertain, the appropriate SBET will be notified and will support the MOT during the recovery process.

To maintain the SBET in a continuous state of readiness, the MOT will provide periodic performance reports to the SBET. The SBET will have access to all engineering telemetry stored on the SDS and will be able to access this from their office personal computers.

MOC workstations will be available to the SBET when direct support of on-orbit operations is necessary. Certainly this will occur during the Early Operations mission phase and most probably during periods of anomaly investigations.

4.4.2 Operations Planning

Operations planning will consist of the following activities necessary to support a scheduled track:

- Track scheduling
- Maintenance activity scheduling
- Managing the uplinking of instrument commands
- SSR management
- Timekeeping management
- Wheel desaturation management
- Navigation management
- Track Plan Generation

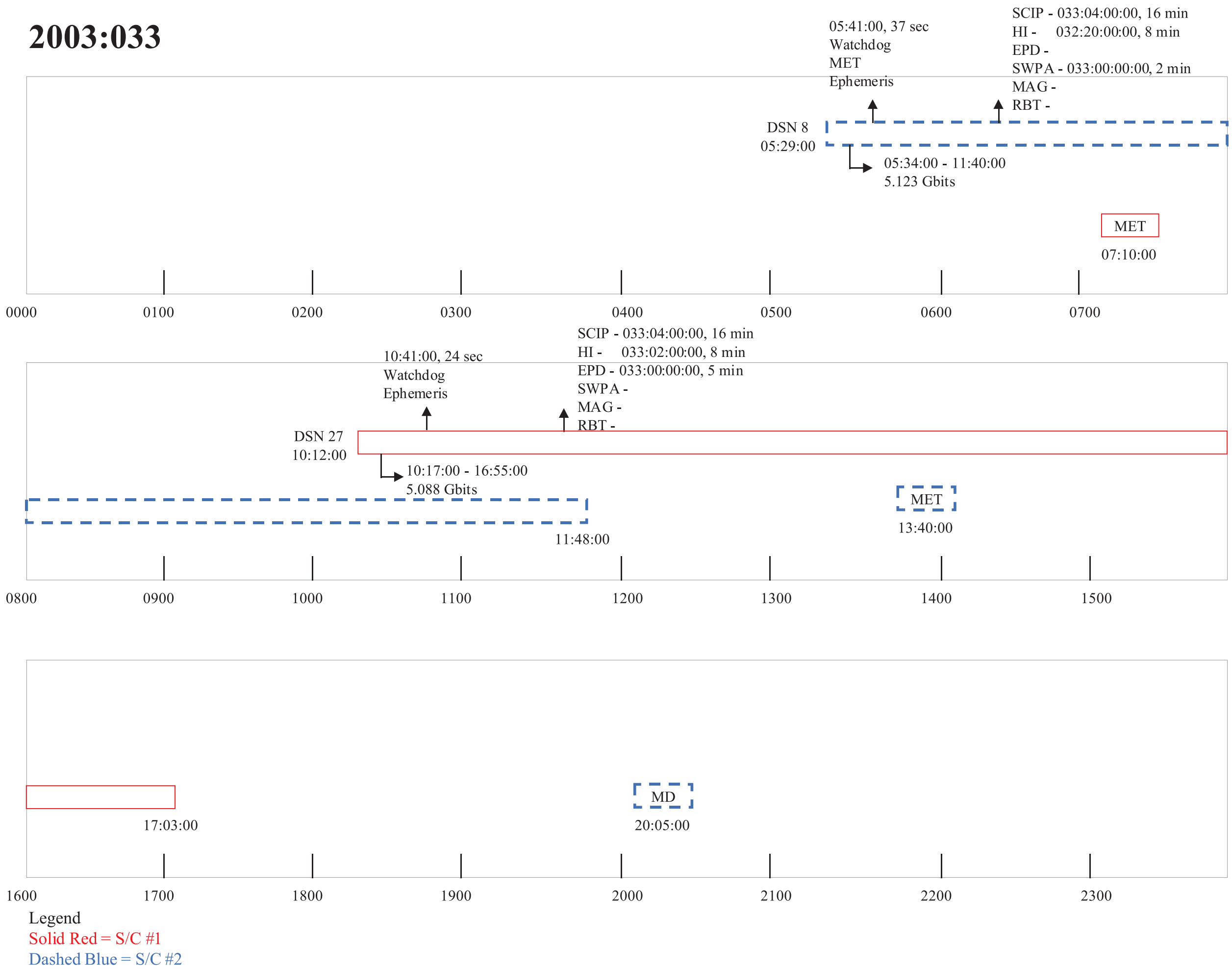

Figure 4-4 Daily Timeline

The STEREO operations' planning consists of planning a week of tracks in advance. The STEREO planning week starts on Monday. For example, on Monday of Week – 1, the MOT will be planning the following week. The MOT will determine the operational requirements of the spacecraft bus over the next week and will prepare the necessary command packets to satisfy these requirements.

Each day, the track schedule for the next day will be reviewed to ensure that it is up to date. A Daily Timeline (Figure 4-4) will be generated graphically depicting the significant operations on both vehicles for the next day. The final daily operations planning task is to generate a track plan.

4.4.2.1 Track Scheduling

The DSN track requirements for each spacecraft will be scheduled well in advance. Unlike most planetary missions, there is no encounter phase for the STEREO mission. Since the prime science phase is continuous, starting shortly after S/C checkout and continuing through to EOL with every track having the same priority.

Nominally, there will be one DSN track per day per spacecraft.

Planned DSN track schedules for both S/C will be stored on the SDS.

4.4.2.2 Maintenance Activity Scheduling

A Maintenance Event (ME) is an activity scheduled on the S/C and executed via commands for the purpose of maintaining the health of any spacecraft bus subsystem or managing the resources of the spacecraft. The MOT is responsible for the evaluation of the spacecraft bus and will plan and schedule all MEs. With the assistance of SBET, the health of the spacecraft will be managed by evaluating component performance and generating command sequences as Maintenance Events.

Maintenance activities for the instruments are the responsibility of the SOC and are not addressed in this document.

There are two categories of MEs, routine and sporadic. A routine ME has a set execution frequency, i.e., every track, daily, weekly, etc. A sporadic ME has no set execution frequency. A sporadic ME will be initiated based on evaluation of the telemetry data. A ME may consist of the following:

- Watchdog timer resets
- Updating the S/C ephemeris
- Updating MET
- Wheel desaturation
- S/C engineering buffer dumps
- Maintaining spacecraft bus macros
- Maintaining autonomy rules
- PPT voltage and temperature adjustments
- Software changes

4.4.2.3 Managing the Uplinking of Instrument Commands

Instrument command packets will be uplinked during each track. These instrument command packets will be prepared, in advance by the SOC for all instruments and will arrive at the MOC no later than two hours prior to the scheduled primary track. In general, however, instrument command packets should arrive well in advance of this deadline. Instrument teams are encouraged to forward command packets only once a week that includes packets designated for uplink each day of the week. Scheduling data, to accompany the command packets, will indicate when to actually uplink these packets. Until then, they will be stored at the MOC. The means by which these command packets are scheduled has been described previously (see Section 2.5.1). Briefly, the command packets will be augmented with two time tags. One time tag will specify the earliest time that the command packet can be uplinked to the instrument and the other will indicate the latest time that this can happen (the expiration time). Those command packets that have a start time exceeded by the next track start time will be queued for uplink at that track to that S/C. Each instrument on each S/C will have its own set of storage buffers, staging and uplink queues, in the MOC.

The MOT has the responsibility of managing the command uplink for all spacecraft commands, to the bus and to the instruments. Accordingly, the MOT must have some knowledge of just what is contained in the instrument uplink queues. The actual instrument commands is unimportant, but the quantity of data to be uplinked is important to the MOT. The scheduled track will offer limited uplink capacity. Nominally, an hour of instrument command uplink time for each track has been set. This translates into approximately 450 kbits of instrument command data for all instruments per track per S/C. Commanding during this interval is not continuous. Rather, the command packets, packed into transfer frames, are uplinked and verified, transfer frame by transfer frame. The verification process can slow the uplink down some. Also, any retransmissions will add additional delays. Therefore, instrument teams are encouraged to operate their instruments as command efficiently as possible.

The MOT will examine each instrument uplink command queues, sorted chronologically by expiration time, to assess the transmission time necessary to uplink the content. MOC software will provide status of the content of the queue including expiration time. The status provided will also indicate estimated transmission time of all queued commands. Further, the time to transmit all the commands in the uplink queues of all instruments will be provided. In Section 2.5.1, the concept of a ‘grocery bar’ was introduced. The purpose of this is to separate, in the active command queue, those packets which will be uploaded during the upcoming track and those which are being purposely held back for a later track. The manipulation of this ‘grocery bar’ by the MOT will provide the necessary traffic control of instrument commands so that the required instrument command packets to be transmitted, along with the real-time and time tagged spacecraft bus command packets, will meet the track uplinking allocation time.

Manipulation of this ‘grocery bar’ is the only control of the queued instrument command packets, except flushing (removing all command packets from) an instrument’s queues altogether. No editing control is available to the MOT. Flushing will only be permitted when authorized by the instrument team associated with that particular queue.

Spacecraft bus commands will receive priority during uplink operations and these can interrupt instrument command uploads. The MOT will actually have control over this process and can withhold spacecraft bus command uplink when necessary. The track plan, prepared by the MOT, will specify precisely what command packets, instrument and spacecraft bus, real-time and time tagged, are to be uplinked during a given track period.

4.4.2.4 Solid State Recorder (SSR) Management

As a baseline, the SSR will be played back on each track. For the STEREO mission, manual MOT management of the SSR will be minimized. This will be done by implementing software on the S/C and in the MOC to monitor CCSDS transfer frames on each virtual channel. It will automatically detect and retransmit missing transfer frames during an SSR playback. The state of the playback reception at the end of a track will be saved for the next track.

Currently, the SSR recorded data is divided into the following four prioritized data streams:

1. G&C Anomaly
2. Engineering Anomaly
3. Science
4. Nominal Engineering

At the beginning of an SSR playback, all G&C and engineering anomaly data is downlinked first, followed by science data, and then nominal engineering data. The amount of SSR data transmitted during a track will vary over the duration of the mission. Initially, the entire SSR will be played back each day. However, as the S/C to Earth range increases, the amount of SSR data played back will decrease. Eventually, during an eight-hour track, the entire SSR cannot be played back.

At the beginning of the mission, the SSR playbacks will be controlled by using real-time commands. As the mission progresses, to save communication time and increase the data downlinked, as a goal, the control of SSR playbacks will transition from uplinked commands to an on board autonomy rule.

An SSR Log will be maintained on the Mission Data Archive in the SDS to provide a chronological history of all science data recovered to date.

4.4.2.5 Timekeeping Management

The Mission Elapsed Time (MET), as generated by the C&DH, will be maintained to the required 0.5 seconds of UTC for each S/C. This will be accomplished by a software process in the MOC that will periodically estimate the time offset, based on the S/C oscillator drift rate along with known system time delays (one-way light time and internal S/C time delays). This time offset or update will be periodically uplinked to the S/C, as a time tagged maintenance event, to maintain the MET requirement.A history of the time updates for each S/C will be maintained in the Mission Data Archive on the SDS.

4.4.2.6 Wheel Desaturation Management

As S/C momentum builds in the RWAs it will need to be dumped periodically using the thrusters in the Propulsion subsystem. The spacecraft will have the capability to autonomously dump momentum. This will occur at four day intervals or greater. In the event that the function is turned off, the MOT will monitor the RWA speeds and send commands, as a time tagged maintenance event, to desaturate the wheels on each S/C. So as not to interfere with the science data collection of the instruments, time will be allotted on a daily basis for possible momentum dumps. If a momentum dump is to occur, instruments will be warned over the 1553 bus.

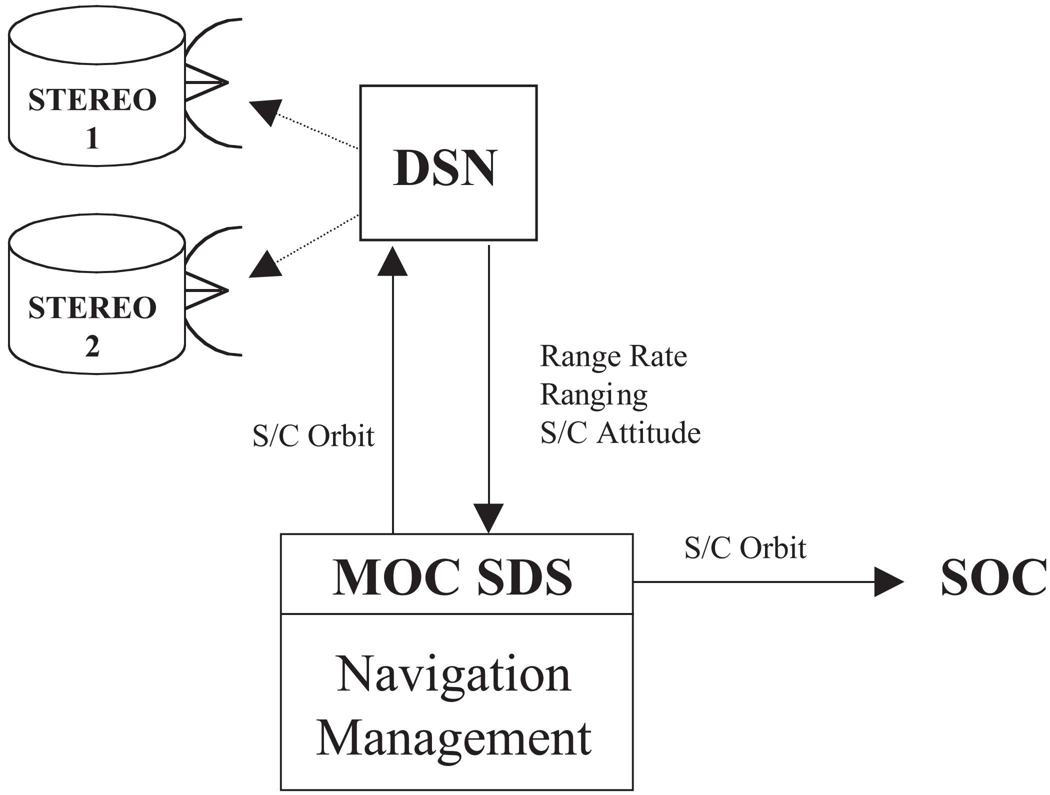

Figure 4-5 Navigation Data Flow

4.4.2.7 Navigation Management

The G&C engineering team at JHU/APL will conduct the navigation management for each S/C. Using the Doppler range rate, ranging, and S/C attitude data, the S/C orbit will be determined using the Goddard Trajectory Determination System (GTDS) (Figure 4-5). Required navigation data will be stored in the Mission Data Archive on the SDS. S/C orbit data will uplinked to the S/C AFC and will be provided to DSN at required intervals for proper antenna pointing.

4.4.2.8 Track Plan Generation

The track plan is the data product that is used by the MOT to conduct a track. After all activities for the track have been scheduled, a track plan will be generated. It will list the following information chronologically:

- S/C ID
- Track ID
- S/C range
- Expected downlink bit rate
- DSN station
- Acquisition of Signal (AOS) time

- SSR Playback start time
- SSR Playback total bits downlinked
- Spacecraft bus command uplink start time
- Spacecraft bus command total bits uplinked
- UT maintenance events (i.e., MET update, momentum dump, etc.)
- Real-time maintenance events
- Instrument command uplink start time
- Instrument command packets earliest uplink time & bit size (for each instrument)
- Instrument command start time total bits uplinked
- SSR Playback stop time
- LOS time

4.4.3 Operations Control

Operations control will consist of those activities immediately prior to and following a scheduled track and will include a pre-pass readiness test and track operation. A pre-pass readiness test of the ground facilities will include the following:

- Data circuits to DSN
- Voice circuits to DSN
- MOC (elements required to support real-time operations)

This testing will assure that the necessary elements of the ground system are functional and properly interconnected as required to support the prepared track plan.

At the conclusion of pre-pass testing, the respective operating teams will make any final configuration adjustments necessary to support the upcoming track.

Spacecraft commanding may only be initiated at the MOC command workstation. Three MOC workstations, protected by the security firewall, will be designated as command workstations, two of these may be activated to support concurrent S/C commanding during the track, the other will be ready as a ‘hot’ backup in case one of the active workstation fails. All MOC workstations may display processed telemetry data from both the spacecraft and the ground system. In general, the active command workstation will be dedicated to only commanding and the verification thereof, and to assure that the track plan is properly executed. The remaining workstations will be used to monitor spacecraft and ground system performance via processed telemetry.

After a track has been completed, an As-Run Track Plan will be generated. It will essentially be a marked-up or as-flown Track Plan and will also list the following:

- Amount of real-time data received
- Amount of SSR data received
- Available SSR space
- Status of all uplinks

The STEREO MOT will transition to unattended tracks after the Early Operations Checkout phase.

4.4.4 Performance Assessment

The objective of the Performance Assessment function is to maintain the health of the spacecraft bus subsystems and evaluate its performance to collect data. Subsystem performance assessment consists of routinely determining the status, configuration, command verification, and performance of each spacecraft bus subsystem. The following assessment tasks will be performed by the MOT:

- Alarmed telemetry processing
- Command verification
- Trend analysis
- Providing data to the SBET

Trend analysis will be conducted on critical subsystem components and on components that are known to degrade with time, e.g.:

- Battery voltage, pressure, temperature, state of charge
- SA temperatures and currents
- Operational and survival heater currents
- Propulsion tank pressure
- Other critical temperatures

These analyses will be conducted on a daily, weekly, monthly, quarterly, and annual basis.

The MOT will maintain a history of the changes to each S/C after launch in a configuration log. This will be used to maintain the S/C during processor resets and also for anomaly investigations. A PC spreadsheet implementation of the configuration logs will be sufficient.

The performance assessment function will be augmented by in-depth analysis of subsystem performance by the SBET. The SBET will have direct access to the engineering telemetry database stored at the SDS so any data may be accessed and processed to the satisfaction of the responsible engineer.

All of the performance assessment processing will be automated. Alarms processing, command verification, and trend analysis plotting will be done automatically. Each day, the MOT will review the output of these assessment processes. This will allow the MOT to minimize the daily time required to determine the health and performance of each spacecraft bus.

A Performance Assessment report for each S/C will be available on the Mission Data Archive in the SDS.

Performance assessment for the instruments is the responsibility of the SOC and is not addressed in this document.

4.4.5 Anomaly Investigations and Resolutions

The MOT is responsible for the safety and health of both S/C buses. They will lead and coordinate investigations with the SBET into all S/C bus anomalies. Anomalies identified both during a track and during performance assessment will be investigated. A cumulative database of all S/C bus anomalies for each S/C bus, from I&T through EOL, will be maintained in the Mission Data Archive on the SDS.

To assist the MOT during unattended tracks, an automated alarm notification system will be implemented. It will consist of an automated paging system that will notify the on-duty MOT staff of any alarms received during a track. Additional supporting engineering data will be emailed to an offsite (e.g., at home) MOT staff for further analysis of the problem. The notified MOT staff can then determine the appropriate action to take, i.e., request additional tracks, download additional engineering data, consult the respective SBET, etc.

4.4.6 Training

Staffing of the MOT will begin early during the development phase of the program. Every MOT staff member will have a detailed knowledge of the operation and constraints of both STEREO spacecraft and the MOS. The MOT will be assigned functional responsibilities necessary to provide both an education and essential tasks in support of the SBET as well as the I&T Team. The MOT will support the spacecraft subsystem engineering teams during the testing of these subsystems prior to delivery to the I&T Team. Components of the actual MOC will be employed to support subsystem testing, development of databases, display formats, data processing, and command sequences, etc., produced to support subsystem tests, may all be brought forward to the spacecraft system level support effort.

The MOT will develop procedures and will support the conduct of acceptance testing of the MOC hardware/software system.

During I&T phase, the MOT will be part of the I&T Team. They will define and produce the necessary system level tests to support the conduct of mission simulation tests. The S/C will be tested in the same manner as it will eventually be operated on-orbit. During the conduct of tests, the MOT Spacecraft Specialists will provide direct support to the Test Conductor as members of I&T Team. During this time, the function of the MOT will be to provide an assessment of the performance of the spacecraft subsystem under test. The MOT will assume the role of the Test Conductor during certain times within the I&T phase.

On-orbit mission simulations, where the spacecraft is operated as if it were on-orbit, will be conducted during the I&T phase. These tests will be conducted by the MOT just as they will during the actual on-orbit phase of the mission. All external operations supporting organizations and facilities (DSN and SOC) will be invited to support these tests. These tests will become the rehearsals of the MOT and the entire MOS.

The S/C Simulator will also be used provide training to new MOT staff after launch.

4.5 Mission Planning Team

The objectives of the MPT are to determine mission priorities, data recording and playback priorities, and manage the consumable resources (i.e., SSR storage, propellant, battery life, flash/EEPROM usage, power and thermal margins) on the S/C. The MOT reports directly to the MPT. It will consist of representatives from the following:

- Sponsor - NASA GSFC
- Lead Scientists
- APL Program Management
- Mission Operations

4.6 Mission Operations Working Groups

Prior to launch, at appropriate times as the development phase progresses, working groups will be organized by the MOT for the purposes of joint-preparation of essential procedures and related documentation that will establish the basis of the spacecraft and ground systems operating procedures.

It is the intent of the MOT to actually prepare the necessary documentation, the content however will require a collaborative effort with the spacecraft subsystems and instruments and all ground system development teams. Working groups will be formed to address the following:

4.6.1 Early Operations Plan

This working group, comprised of the MOT and SBET will establish the operational procedures necessary to conduct spacecraft bus operations between launch vehicle separation and until the spacecraft is declared operational.

4.6.2 Spacecraft Operating Rules and Constraints

This working group, comprised of the MOT and SBET, will identify rules and constraints to be imposed upon the spacecraft bus users and the MOT.

4.6.3 Spacecraft Autonomy Rules and Procedures

This working group, comprised of the MOT and SBET, will specify autonomy rules and the on board command sequences for the safe and efficient operation of the spacecraft bus.

4.6.4 Spacecraft and Ground System Contingency Plans and Procedures

This working group, comprised of the MOT, SBET and ground system development teams, will identify potential contingency situations for both S/C and the MOC.

4.6.5 Mission Operations System Processes and Interfaces

This working group, comprised of representatives of all elements of the total STEREO on-orbit operations support system (DSN, MOC and SOC) will address issues related to the overall ground system, hardware, software, teams, and procedures.

5.0 Operational Scenarios

5.1 Normal Operations

The Normal Operations scenario depicts the STEREO mission operations after both S/C have been checked out on-orbit. It is assumed that the range to both S/C is such that both SSRs can be played back in their entirety during their respective tracks. It does not consider operations during an anomaly on the S/C and/or the ground system.

The normal operational mode of the S/C consists of all instruments powered on, time tagged command capability enabled, the X-axis pointing at the Sun, and the HGA pointing at the Earth.

Upon arrival in the morning, the S/C Specialists will review all results from routine processes. This includes routine performance assessment plots, S/C alarm processing, As-Run Track Plans, instrument command queues, timekeeping management, SSR management, wheel desaturation management, and MOC and SDS equipment status. All S/C and MOC anomalies will be investigated and sporadic maintenance activities will be generated. Daily DSN scheduling activities, including track schedule generation, teleconferences, etc. will be performed.

During a spacecraft track, the MOT manages the flow of uplink command packets to the entire spacecraft. The flow of these commands is monitored to assure successful delivery to the destination. Automatic retransmission may be initiated if delivery is unsuccessful.

The downlink of real-time and SSR playback data are initiated under the control of the MOC. Real-time spacecraft bus engineering telemetry is converted to engineering units and tested against prestored acceptable limits and selectively displayed on visual media. Engineering telemetry that is played back is stored on the SDS. All science data and engineering telemetry from the playback are sent in a file format to the SOC via the SDS in near real-time.

5.2 Prelaunch

To be determined.

5.3 Early Operations

The Early Operations phase extends from launch vehicle separation to the declaration, by the Mission Planning Team, that the spacecraft bus and all instruments are capable of supporting the mission objectives. This phase encompasses launch load preparation through on-orbit checkout and evaluation. The launch load consists of a command sequence that will control, chronologically, critical spacecraft bus operations immediately after separation from the boost motor. These commands will provide:

- Deployment of solar panels
- Initiation of safe-hold mode attitude capture
- Powering on the IEM
- Initiation of the first track

The S/C separation sequence triggers the pre-stored launch load command sequence in the C&DH subsystem. This sequence will sustain spacecraft operations until the first scheduled DSN track occurs. The MOT, upon evaluation of the performance of the spacecraft bus at that time, may choose to alter the planned operational sequence or may elect to continue with the stored launch load sequence until the next scheduled track.

The primary activity during this Early Operations phase will be to checkout the subsystems and instruments on the S/C. The STEREO MOT will depart from the normal operations staffing plans to provide a more or less continuous 24-hour/day support. For the first few days, more than one DSN track per day will be requested. The Early Operations phase will be supported by combined MOT, SBET, and instrument teams all located at the MOC. Launch operations teams may also be utilized as required. Using the Space Shuttle for launch may increase the MOT staffing slightly for the first few weeks due to simultaneous checkout of both S/C.

5.4 Operations During Anomalies

The top priority for the MOT will be to maintain the S/C. When an anomaly is detected on the S/C, all necessary resources will be employed to resolve the anomaly with minimal mission impact.

There are three operational modes of each STEREO spacecraft; Operational, Safe Hold, and Earth Acquisition. Should an anomaly occur that degrades the Operational mode of the S/C, the S/C will autonomously transition to Safe Hold mode. This mode is designed to conserve power and configure the S/C for communications with ground system. For Safe Hold mode, the roll axis is controlled to point the X-axis within 1^0 of the Sun and the narrow angle (emergency) MGA within 1^0 of the Earth. All instruments will be powered down autonomously and time tagged commanding will be disabled.

If an anomaly occurs that degrades the Operational or Safe Hold modes of the S/C so that the roll axis is not known by the G&C subsystem, the S/C will autonomously transition to the Earth Acquisition mode. This mode is designed to conserve as much electrical power as possible and configure the S/C for communications with ground system. For Earth Acquistion mode, the AIE will use measured coarse sensor data to point the X-axis to within 1^0 of the Sun and rotate, or roll, the S/C at 1^0 per minute. This slow rotation will allow the MOT to re-establish communications with the S/C using the narrow angle (emergency) MGA once every three hours. The MOT can then stop the S/C rotation and download the necessary SSR data to determine the cause of the anomaly. All instruments will be powered down autonomously in this mode and time tagged commanding will be disabled.

The SOC will be notified via email of all anomalies that effect the mission.

5.5 End of Life (EOL)

The EOL for each S/C will be determined by the MPT. At that time, the S/C will be configured to conserve remaining resources. The necessary documentation, hardware, and software for re-establishing communications and operations of each S/C will be archived.

6.0 Acronyms and Abbreviations

AFC	Attitude Flight Computer
AIE	Attitude Interface Electronics
APL	Applied Physics Laboratory
BWG	Beam Wave Guide
C&DH	Command and Data Handling Subsystem
CCDSDS	Consultative Committee for Space Data Systems
CME	Coronal Mass Ejection
CONOPS	Concept of Operations
DSAD	Digital Solar Attittude Detector
DSN	Deep Space Network
EOL	End of Life
EPD	Energetic Particle Detector
FOV	Field of View
G&C	Guidance and Control Subsystem
GSFC	Goddard Space Flight Center
HGA	High Gain Antenna
HI	Heliospheric Imager
I&T	Integration and Test

ICD	Interface Control Document
IEM	Integrated Electronics Module
IMU	Inertial Measurement Unit
JHU	Johns Hopkins University
LGA	Low Gain Antenna
LVS	Low Voltage Sense
MAG	Magnetometer
ME	Maintenance Event
MET	Mission Elapsed Time
MGA	Medium Gain Antenna
MOC	Mission Operations Center
MOS	Mission Operations System
MOT	Mission Operations Team
MPT	Mission Planning Team
OSC	Ultra Stable Oscillator
PPT	Peak Power Tracker
RBT	Radio Burst Tracker
RS	Reed-Solomon
RWA	Reaction Wheel Assembly
S/C	Spacecraft
SA	Solar Array
SBET	Spacecraft Bus Engineering Team
SCIP	Solar Coronal Imaging Package
SOC	Science Operations Center
SDS	STEREO Data Server
SSR	Solid State Recorder
STEREO	Solar TErrestrial Relations Observatory
STF	Supplemented Telemetry Frame
STP	Supplemented Telemetry Packet
SWPA	Solar Wind Plasma Analyzer
TF	Telemetry Frame
TP	Telemetry Packet
UTC	Coordinated Universal Time
XB	X-Band